MINIMUM ENERGY QUADRATIC PROGRAMMING METHOD FOR LINEAR CIRCUITS, LOAD FLOWS AND OPTIMIZING GENERATOR DISPATCH

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Abstract

Improved operation and comprehension of analysis tools are required in this era of rapid changes in electrical power system structure, electricity market regulations and operation. In this paper a brief introduction and worked example of a proposed formulation of generator dispatch utilizing suitable optimisation techniques to minimise an objective (energy) function while satisfying Ohm's law and Kirchhoff's Current law is presented. The formulation of this Minimum Energy State of System (MESoS) perspective can be used to solve circuit problems, load flows and optimising generator dispatch problems. The aim of this paper is to present this consistent solution perspective and so make some contribution towards improved understanding and communication of power system analysis methods and results. Finally, this MESoS concept is applied to a standard 6 bus test power systems.

1. INTRODUCTION

Electricity Supply Industries (ESI) in many countries has recently been restructured (deregulated) with the intention of introducing competition into energy generation and retail energy sales. This restructuring and the endless search for increasing returns on capital investment have increased the pressure for improving the efficiency of the utilization of all power system resources components and staff. These pressures increase the need for flexible, accurate and fast tools to analyse and optimise power system operation. To maximise the efficiency of staff, the operation and outputs of these analysis tools need to promote improved comprehension and communication.

After this market based restructuring of the ESI, individuals with little power systems engineering experience are increasingly involved in designing market regulations and the minute by minute trading of electrical energy and energy contracts. The majority of these individuals wish to understand the operation of power systems, have the intelligence but not the time and so look to power system engineers to offer consistent and simpler explanations of the electricity theory.

In this paper we present a different view on approaches to solving electrical circuits, power system load flows and Optimum Power Flows (OPF) in an attempt to offer a consistent self contained explanation of power system analysis methods. This different view leads to a method of solving circuits, load flows and OPF's all by one method.

Firstly, a brief introduction is given into the theory behind the proposed quadratic optimization method that minimises apparent power losses which is the solution to electrical circuit problems. The perspective is designed to find the solution at the minimum energy state of the electric system (circuit) and so in the paper is identified by the acronym MESoS (Minimum Energy State of System). This MESoS perspective of electrical circuit analysis is based on an energy point of view. Thus the analysis is similar to Tellegen's Theorem: "The total power is zero *{into or out of a network}*, provided the elements in the network obey Kirchhoff's laws" [1]. In developing this MESoS perspective the energy analysis of a circuit is approached from a slightly different starting point (Kirchhoff's Laws arising from energy conservation instead of Kirchhoff's Laws leading to a proof of energy conservation) and a different order of reasoning to the description of Tellegen's theorem as expressed by Penfield [2]. However, the energy view utilized to develop the proposed MESoS perspective is essentially an application of Tellegen's theorem. This independent line of reasoning leads to a different problem formulation. For load flow and OPF problems the results are the same as for Incremental Transmission Losses (ITL) OPF [3], [4] solutions.

To further explain the MESoS perspective, a worked example on a simple three-bus power system is presented. Then to show the effectiveness of MESoS perspective for small power systems, results are presented for a 6 bus IEEE standard test system. The MESoS perspective was also tested on a standard 14 bus system; these results are same as standard load flow solutions and are not shown in this paper due to space limitations.

2. THREE SOLUTION TYPES REQUIRED IN ELECTRICAL ENGINEERING

In electrical power engineering discipline three different solution methods are used. These are: linear electrical circuit analysis, load flow solution and OPF methods. Each solution method is different enough to require a new understanding, which complicates the explanation of each individual solution method.

2.1. Electrical Circuit solutions

For (linear) electrical circuits with a unique solution, the solution is found by solving a set of linear simultaneous equations shown in matrix form in (1). This set of linear simultaneous equations is built from Ohm's Law and any combination of Kirchhoff's Current or Voltage Law involving the linear variables of Voltage (V), current (I) or impedance (Z):

1) Ohm's Law

2) Kirchhoff's Current law AND/OR Kirchhoff's Voltage law

Most electrical circuit problems have only one possible (unique) solution. As an example if all node voltages are known and the currents need to be calculated then the problem has only one possible solution in the form (1).

$$[V]=[Z][I] \quad or \quad [I]=[Y][V] \qquad (1)$$

2.2. Power system load flow theory

In power systems analysis energy is the primary concern, so we define electrical circuits in terms of power. If any constraints are defined in terms of power, then the I^2R relationship between current and power means linear superposition fails. The circuit can not be solved by a set a linear simultaneous equations because the relationship between powers, voltages and currents are quadratic (2).

S = II*Z =|I|2Z = |V|2/Z (2)

Where S is the complex power, I and V are the currents and voltages, respectively and Z is the impedance.

Load flow problems are solved for a power system by calculating the bus voltages given known real (P) and reactive (Q) powers at each load bus. If only one bus (the slack bus) in the electricity system is allowed to change power values then the load flow is forced to only one possible (unique) solution. This load flow problem can not be solved by linear simultaneous equation technique and so is traditionally solved iteratively either by Gauss-Seidel or by Newton–Raphson methods. This is an optimization problem where the objective of each iteration is to minimise the power mismatch or calculation error. The power mismatch is the difference between the known bus powers and the calculated powers. In traditional load flow methods the calculated powers are expressed in the form of the powerflow equations (3) and (4) [5].

$$P_j = \sum_{k=1}^{k=K} \left|Y_{j,k} V_j V_k\right| \cos\left(\theta_{j,k} + \delta_k - \delta_j\right) \quad (3)$$

$$Q_j = -\sum_{k=1}^{k=K} \left|Y_{j,k} V_j V_k\right| \sin\left(\theta_{j,k} + \delta_k - \delta_j\right) \quad (4)$$

Where P, Q, Y, V,θ and δ have their usual power system meanings.

2.3. Optimum Power Flow OPF

The OPF is used to dispatch generation to satisfy a desired objective function. The most common objective function is to dispatch generation to minimise short-run (market based) or long-run (monopoly) total system costs [6]. Logically, the load flow form of expression (3) and (4) is carried into the formulation of methods of quadratic programming optimization of the OPF [7].

Minimise objective function f(x)

Subject to power equations (3) and (4)

and subject to system constraints, such as voltage magnitudes and generator loading limits.

The main aim in this paper is to provide a generalized solution technique to solve electrical circuits, load flows and OPF's.

3. THEORY OF MINIMIZING ENERGY STATE OF SYSTEM (MESOS) PERSPECTIVE

To possibly provide a more consistent general solution to the three problems of circuits, load flows and OPF's, the development of the perspective in this paper is based on two fundamental concepts of physics and so of electrical engineering:

1) Physical system solution is at the minimum energy state, most often expressed in Ohm's Law form.

2) Energy Conservation expressed as Kirchhoff's current law or Kirchhoff's voltage law

Any electrical circuit or power system must satisfy energy conservation expressed as Kirchhoff's Current law and minimum system energy state expressed as Ohm's law. The set of possible or feasible solutions for a power system are the set of system solutions that satisfy both Kirchhoff's Current law and Ohm's law. It is noted that all power, voltage and current expressions in the following derivations are phasor quantities ('vectors') with real and reactive components and that all impedances are actual line impedances not values from the system admittance matrix. Here P is represented by the real power and Q is represented by the reactive power.

3.1. Minimum Energy State

The natural steady state condition of any physical system including electrical circuits is the minimum energy state. In electrical circuits the instantaneous minimum energy state is the state that minimises the complex power losses in the circuit. So the solution is found when the power losses are minimised where the power losses are equal to the current squared multiplied by the impedance. This minimum energy state is most usefully and elegantly expressed in the form of Ohm's Law.

3.2. Kirchhoff's Current law from Tellegen's Theorem

Energy cannot be created or destroyed, so at any point (bus) in an electricity system (with N buses) the sum of energy into the point must equal the sum of energy out of that point. Writing this in terms of power gives, power injected into a bus equals the sum of all power flowing out of that bus [8].

$$S(j) = \sum_{k=1}^{N} S(j,k) = \sum_{k=1}^{N} P(j,k) + jQ(j,k) \qquad (9)$$

Where S(j) is the complex power injection into bus j. The power injection S(j) is positive for generation at bus j and negative for a load. Using the π transmission line model, line capacitance is included in the bus 'load' S(j). S(j,k) is the power flow from bus j to bus k as measured at bus j. Note because of line losses I2Z, S(j,k) ≠ -S(k,j) that is power into line j,k will not be equal to power out of line j,k.

All power flows into or out of bus j can be expressed as the bus voltage V(j) multiplied by the complex conjugate of the current S(j,k)=V(j)I(j,k)*. The current law expression (10) is computationally simpler to implement than the power expression (9) as the current has directional flow symmetry I(j,k)=-I(k,j), when line capacitance currents are included in the bus injection currents I(j) and I(k).

$$I(j) = \sum_{k=1}^{N} I(j,k) \quad \forall\, j = 1 to N \qquad (10)$$

3.3. Objective Function

For electrical circuits (with unique solution) the objective function must be to minimise power losses. In the solution of load flows we normally force to have a unique solution by fixing all bus real powers to constants except the slack bus; the objective must be to minimise transmission line losses.

The same general format of the MESoS perspective can be applied to solve electric circuit problems, load flows and OPF's by changing the objective function. However when this general format is used for the load flow (where only one slack bus is allowed) is made redundant. Only one slack bus is used in load flow studies to force one unique solution. If all bus powers are allowed to vary the 'load flow' has multiple solutions and so becomes an OPF problem.

Any system solution that satisfies both Ohm's Law and Kirchhoff's Current Law is a feasible solution that is physically possible (subject to other system constraints). Once this feasible set of solutions is defined, the best or optimum solution can be determined based on a carefully designed objective function that rewards any mix of outcomes desired by the ESI community. The objective function may include outcomes such as:

A. minimizing total power system costs
B. maximizing profit
C. minimizing emissions of CO2
D. minimizing pollution (oxides, particles etc)
E. minimizing fuel consumption
F. dispatch generators and utilize system lines to maximise power system reliability
G. maximise social benefit and fairness

Or ANY mix of weighted outcomes

Example: maximise Total benefit = 5% B + 10% C + 20% D + 10% E + 5%F + 5%G + 45% A (minimise cost)

To allow comparison between solutions to (linear) circuits, traditional load flows, (OPF) load flows and simplify the explanation in this paper we define our objective function so that the generators (or variable loads and reactive power devices) are dispatched to minimise the total system (complex) power losses.

3.4. Formulation of MESoS

For any non cost OPF's applicable to circuits, load flows and (OPF) load flows the objective is to solve a system such that total (apparent) power losses are minimised;

then the general solution optimization can be written as (11):

Minimise total apparent power losses (objective function)

$$\left| \sum_{j=1}^{N} \sum_{k=j+1}^{N} \left| I(j,k) \right|^2 . Z(j,k) \right| \qquad (11)$$

By adjusting the line currents I(j,k) and bus voltages V(j).

Subject to the feasibility constraints

1) Power injection constraints

$$S(j) = P(j) + jQ(j) = \sum_{k=1}^{N} S(j,k)$$

$$= \sum_{k=1}^{N} V(j).I(j,k)^{*} \quad \text{for all buses } j = 1toN \qquad (12)$$

Or in Kirchhoff's Current law form current injection at bus j

$$I(j) = \sum_{k=1}^{N} I(j,k) \quad \forall\ j = 1toN \qquad (13)$$

2) Ohm's Law

For impedance the voltage difference between two buses is

V(j) – V(k) = V(j,k) = I(j,k) . Z(j,k) for all j and k 1 to N

Also subject to System constraints

Voltage magnitude constraints

V(j)minimum < |V(j)| < V(j)maximum

Transmission line current constraints

I(j,k) < I(j,k)maximum

Generation loading constraints

Gp(j)minimum < Real power Gp(j) < Gp(j)maximum

Gq(j)min < Reactive power Gq(j) < Gq(j)max

In addition to any other constraints required for that system.

Minimising energy state is equivalent to Ohm's Law. So for linear circuits and load flows (with unique solution) including both the Ohm's Law constraint and energy state minimisation objective function is redundant. These problems could be solved by applying only KCL and Ohm's Law. However, the general form is used so the same problem formulation can be applied to all types of problems.

4. LOAD FLOW EXAMPLE

The MESoS load flow perspective is first explored by presenting a simple example for a trivial power system with two generators and one constant load displayed in Fig. 1. To solve as a traditional load flow the generation at bus two is defined to be constant at 50MW +j 30MVAr.

Applying the general equations to the system in Fig. 1 and substituting system values while setting the voltage magnitude and angle at bus 2 to V(2) = 110+j0 [kV] gives:

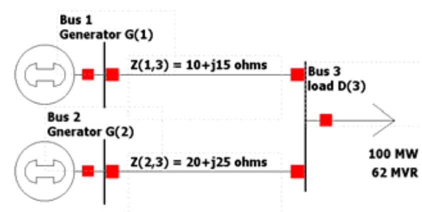

Fig. 1 One-line diagram of 3-Bus power system.

Minimise apparent power losses

$$|\{ |I(1,3)|^2.Z(1,3) + |I(2,3)|^2.Z(2,3) \}|$$

By adjusting currents I(1,3) and I(2,3)

And voltages V(1) and V(3)

Subject to feasibility constraints

1) Power injection constraints

At bus 2 $S(2)=P(2)+jQ(2)=50+j30 = V(2).I(2,3)^{*}$

At bus 3 $S(3)=100+j62 = V(3).I(1,3)^{*} + V(3).I(2,3)^{*}$

2) Ohm's Law over the two transmission lines is the system

V(1)-V(3) = I(1,3).(10+j15)

V(2) – V(3) = (110+j0)-V(3) = I(2,3).(20+j25)

5. (OPF) LOAD FLOW EXAMPLE

To solve the above load flow problem as an Incremental Transmission Losses (ITL) OPF [3], [4] only requires the power injection feasibility constraint at bus 2 to be relaxed. When using the MESoS perspective the difference between load flow and (OPF) load flow is in calculation only, not a difference in methodology. When solving as a load flow there is a unique solution, when solving as an ITL OPF there are many feasible solutions.

The set of feasible solutions is all sets of line currents and bus voltages that satisfy both feasibility constraints. The generation at bus 1 and 2 is calculated from the line currents and bus voltages. To visualize this optimization problem the set of feasible solutions (called the feasible region) is plotted in Fig. 2 by setting the real and reactive generation at bus 2 and then calculating the required generation at bus 1 and the total system apparent power losses. The voltage at bus 2 must be set to a fixed magnitude and angle so that the feasible region can be plotted one three dimensional graph. Once the voltage at bus 2 is fixed the transmission losses, other bus voltages and generation required from bus 1are all functions of the real and reactive generation at bus 2. Thus, the system is only two dimensional. The traditional load flow with fixed generation at bus 2 is represented by one point on the feasible region in Fig. 2.

Please note without maximum voltage constraints, the minimum losses will be when current is minimised and so the voltage tends to infinity. On the x-axis reactive generation at bus two is varied from -30 to +70 MVAr. The y-axis shows the variation of real generation with the total system losses plotted in the direction of the z-axis. The losses are minimised when the generation at bus 2 is 30.49MW and 16.12MVAr (as shown in the Table 1) in the centre of the lightest region of the surface in Fig. 2.

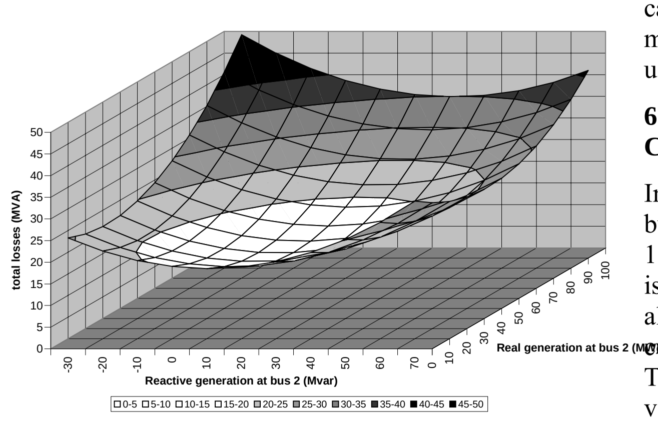

Fig. 2. Plot of total 3-Bus system power losses against changes in generation at bus 2

If the voltage at bus two is not constant then even this very small system has 10 (5×2) adjustable variables in the change set, the real and reactive parts of three bus voltages and two line currents. These 10 variables are not independent and so the number of variables and equations could be reduced. The line currents could be written as functions of bus voltages or vice versa. However, the formulation of the problem shown above enables this standard formulation to cover the largest possible set of system conditions and gives the MESoS perspective greater flexibility. Any bus voltage or line current can be set to constant values without changing the MESoS formulation.

TABLE 1

RESULTS FOR 3 BUS EXAMPLE WITH NO SYSTEM CONSTRAINTS

Power variable	Buses	Real [MW]	Reactive [MVAr]
Total generation		109.28	75.43
Total losses		9.28	13.43
Generation	1	78.79	59.31
Generation	2	30.49	16.12
Load	3	100.00	62.00
System variable		magnitude	Angle [º]
Voltage [kV]	1	115.29	0.63
Voltage [kV	2	110.00	0.00
Voltage [kV	3	100.87	-2.27
Current [kA]	1 to 3	0.86	-36.34
Current [kA]	2 to 3	0.31	-27.86

This is a small system with a ‘well behaved’ cost surface with one global minima and no local minima and so can be solved with any standard optimization package capable of solving quadratic optimizations by numerical methods. The results presented here, were generated using the SOLVER addin of EXCEL.

6. SIMPLE EXAMPLE WITH SYSTEM CONSTRAINTS

In the first solution of the three bus system the voltage at bus two is fixed to an arbitrarily chosen constant 110[kV], in this second solution the voltage at bus two is allowed to be any value between 94 and 110[kV]. To allow a more realistic power system conditions, system constraints are included in the optimization formulation. The reduction in the system feasible region due to the voltage magnitude at bus-1, system constraint is displayed in Fig. 3. Similarly, other system constraints reduce the size of the system feasible region. If the optimization technique used is robust for the system under study then if no solution can be found the system constraints cannot be satisfied or visually the system feasible region is non-existent (Fig. 4) and obviously contains no solutions.

The objective function and feasibility constraints are the same as for the load flow on page 4 with additional system constraints as shown below.

System constraints for the 3-bus example system:-

Voltage magnitude constraints

$$94 <= |V(1)| <= 110 \text{ [kV]}$$
$$94 <= |V(2)| <= 110 \text{ [kV]}$$
$$94 <= |V(3)| <= 110 \text{ [kV]}$$

Current magnitude constraints

$$|I(1,3)| <= 1.0 \text{ [kA]}$$
$$|I(2,3)| <= 0.4 \text{ [kA]}$$

Generation constraints

$$92 <= P(1) <= 100 \text{ [MW]}$$
$$0 <= Q(1) <= 40 \text{ [MVAr]}$$
$$0 <= P(2) <= 100 \text{ [MW]}$$
$$0 <= Q(2) <= 100 \text{ [MVAr]}$$

Applying these system constraints to our example system in Fig.1 gives the minimum apparent loss solution results displayed in Table 2.

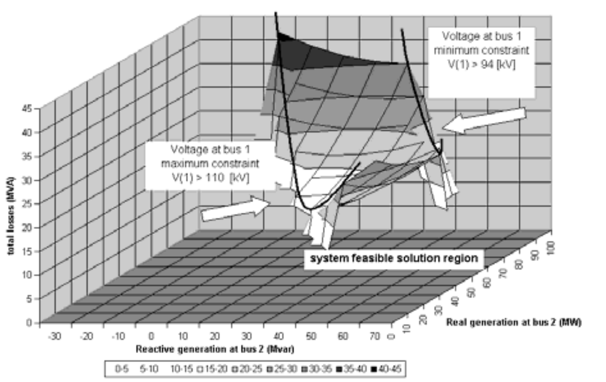

Fig. 3 Plot of total 3-Bus system power losses against changes in generation at bus 2 applying voltage at bus 1 magnitude constraints

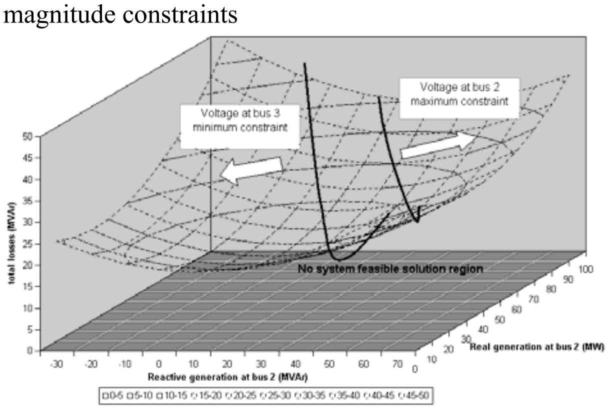

Fig 4 Plot of system with no solution. System constraint different to 3-bus system solved as an example

Using the MESoS perspective the (OPF) load flows are solved as ITL OPFs and so no slack bus is required only a voltage angle reference bus must be selected.

Satisfying the system constraints increases the total apparent power losses from the no system constraints value of 16.33 MVA to 19.97MVA. So satisfying the system constraints comes at a cost of increasing system losses. One useful strength of the MESoS perspective is that the Lagrangian multipliers (λ) calculated during the optimization gives a measure of the relative importance of each system constraint. All optimization based OPF's solutions produce Lagrangian multipliers.

TABLE 2

RESULTS FOR 3-BUS SYSTEM WITH ALL SYSTEM CONSTRAINTS

Variable	buses	Real [MW]	Reactive [MVAr]
Total generation		111.44	78.37
total losses		11.44	16.37
generation	1	92.00	40.00
generation	2	19.44	38.37
Load	3	100.00	62.00
		Magnitude	Angle [º]
Voltage [kV]	1	110.00	2.24
Voltage [kV]	2	108.93	-4.58
Voltage [kV]	3	96.59	-3.05
Current [kA]	1 to 3	0.91	-21.26
Current [kA]	2 to 3	0.39	-67.72

All system solutions were checked with Powerworld simulation software [9]. Results from Powerworld simulations and MESoS results were found to be within 0.1%. The results agreed as both the MESoS optimization and the PowerWorld simulation were solved with error tolerances set to 0.1%. The PowerWorld results were obtained by converting the (OPF) load flow to a standard load flow by fixing the power and voltage settings of the generator at bus one to the values found by the MESoS perspective and defining the generator at bus two as the slack bus at the nominal voltage equal to that found by the MESoS perspective.

7. APPLICATION TO LARGER SYSTEM

The load flow technique as used in the PowerWorld software and the MESoS perspective were applied to two power system models to test the robustness of the MESoS perspective. For all load flow results the agreement between the PowerWorld results and MESoS results were within 0.02% of each other (error tolerance set to 0.02%). The conclusion is that with appropriate simulation accuracy selection the MESoS results are identical to traditional power flow results.

The MESoS perspective was first applied to a six bus (Fig. 5) example power system [10] to further compare this perspective to traditional load flow solutions. In the first solution the power system is solved in a traditional load flow methodology by setting the MESoS settings as in Table 4. With no other information the real power generation at buses 2 and 3 are arbitrarily fixed at 70 MW and the reactive generation is varied to give bus voltage magnitudes of 230kV.

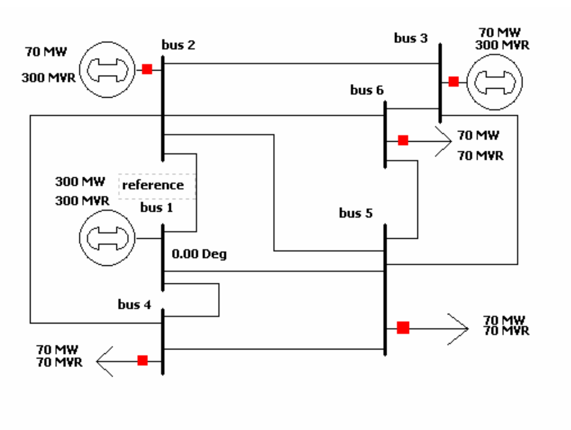

Fig. 5. One-line diagram for six-bus power system, Maximum generation constraints shown for example from table 4

The second solution utilizes MESoS to set reactive generation to solve the (OPF) load flow by minimizing the total system apparent power losses. The voltage magnitudes at buses 2 and 3 are no longer set to 230kV but can vary between 200 and 250kV (Table 5). The reactive generation values obtained from the MESoS solution are used to set the reactive generation at buses 2 and 3 in the load flow. Note: to do this the automatic voltage regulation (AVR) at the buses must be disabled. The flexibility in reactive generation reduces the power loss from 28.78MVA to 28.58MVA. This system is very strong from a reactive power point of view, which can be concluded by examining the Lagrangian multipliers for reactive power constraints.

TABLE 4

SYSTEM CONSTRAINTS FOR STANDARD LOAD FLOW

Bus	$\lvert V_{(max)} \rvert$ (kV)	$\lvert V_{(min)} \rvert$ (kV)	P_{min} (MW)	P_{max} (MW)	Q_{min} (MVAr)	Q_{max} (MVAr)
1	230	230	0	300	-300	+300
2	230	230	0	70	-300	+300
3	230	230	0	70	-300	+300
4	200	250	-70	-70	-70	-70
5	200	250	-70	-70	-70	-70
6	200	250	-70	-70	-70	-70

The third solution is solved as we propose by the MESoS perspective by optimising real and reactive generation to minimise apparent power losses. The voltage magnitude at bus 1 (the slack bus) is fixed at 230kV to simplify comparison. The optimized real and reactive generations obtained by MESoS are set in the traditional load flow method. In comparison to the first solution this reduces the total system losses to 26.89MVA.

In the fourth solution the MESoS perspective is used to its full extent to solve the full ITL OPF in which only the generation limits and voltage magnitude limits are set. Thus the system must solve so that voltages at the generators are less than the maximum limits and voltages at the loads are greater than the minimum limits. As would be expected to minimise power losses, voltage magnitudes are maximised. The apparent power losses are reduced to 22.78MVA.

TABLE 5

CHANGES TO SYSTEM CONSTRAINTS FOR MESOS METHOD

Simulation settings	Changes to Constraints	Total power losses MVA	Total real loss MW	Total react. losses MVAr
Initial system settings for standard load flow	As in TABLE IV	28.77	9.30	27.32
Reactive generation optimized by MESoS	$230 < \lvert V(2) \rvert < 250$ [kV] $230 < \lvert V(3) \rvert < 250$ [kV]	28.58	9.09	27.09
Real and reactive generation optimized by MESoS	$0 < P(2) < 300$ [MW] $0 < P(3) < 300$ [MW]	26.89	8.88	25.38
Buses constrained by voltage magnitudes.	$230 < \lvert V(1) \rvert < 250$ [kV]	22.78	7.23	21.60

In an attempt to show these solutions are at global minimums and not local minima in each of the above four solutions the initial values of currents and voltages in the MESoS perspective were set to random values. For real currents the random values were between –1 and +1 [kA] and for real voltages between –70 and +530kV with reactive voltages set to random numbers between –100 and +100kV. Each of the four solutions were solved by the MESoS perspective ten times utilising ten different sets of random initial values. Every solution was identical to within 0.02% ,which were the defined optimisation tolerances. This by no means extensive set of 44 tests supports our claim that the power system solution given by MESoS is unique having only one global minimum. We recommend for optimisation speed that the standard load flow initial values are used, that is all values equal to one per unit.

This approach was applied for a 14 bus power system based on the system obtained from the Washington State University [11] with same results as standard load flow and the same conclusions as for the six bus system. All MESoS and PowerWorld results agreed to within 0.1% which was the chosen optimisation tolerance. Hence the result from the 14 bus system is not presented in this paper.

8. SCOPE, DISSCUSIONS, LIMIATIONS AND FUTURE WORK

The work presented in this paper is of a preliminary nature posing many questions and at this stage with few answers. Many issues must be addressed before a conclusion can be reached to, if our perspective assists communication let alone if the MESoS is practical for power system analysis. The scope of this paper is of an introduction paper to promote important technical discussions.

The authors acknowledge some clear computational advantages of the power equation (3), (4) formulation of OPF problems. The decoupling of real and reactive powers with voltage magnitude and angle is one clear computational advantage. Other matrix methods such as eigenvectors help to highlight the advantages of the standard form of the system admittance matrix. Future investigation is required into the computational efficiency of the MESoS perspective and ideas are needed to improve this computational efficiency.

9. CONCLUSIONS

The perspectives and results presented are not computationally superior to methods and results in the literature. The author’s goal is to approach the fields of circuit solutions, load flows and OPFs from a different perspective and so make contribution to promote discussions and ideas in these fields.

The MESoS perspective general solution form is a quadratic optimization with the objective to minimise power losses. This optimization must satisfy the feasibility constraints of KCL and Ohm’s Law. Any system constraints can be added to the optimization problem as required. This form of the MESoS perspective can be used to solve electric circuits and load flows.

The MESoS perspective was applied to analysis problems in three example power systems. The results agreed with standard power system analysis methods showing the MESoS solutions were equivalent to these standard methods.

10. ACKNOWLEDGMENTS

The authors wish to present a different viewpoint on a huge body of excellent work. To develop towards practical implementation would need to consider methods such as used by [12-15].

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